Date Observations on Locomotion Parameter of Sport Horses : SHS Performer vs. Barefoot

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Abstract

In Phase 3 of the SHS study, the effects of the glued hoof protection SHS Performer were investigated in comparison to barefoot conditions, focusing on sport horses' functional locomotion. Using high-resolution inertial sensor data (Alogo Move Pro), over 20 biomechanical parameters were analyzed during regular training and under jumping course conditions. The results show significant improvements in stride length (+45 cm), stride dynamics (Stride Ratio +1.23), and energy efficiency (−0.45 kcal per stride) under the Performer condition. Balance metrics revealed enhanced lateral control on curves and more consistent landing stride lengths. In terms of jumping technique, horses with Performer showed a markedly steeper take-off angle (+13°) and 15% higher regularity. The data support the assumption that glued-on hoof protection offers biomechanical advantages that can improve both performance and injury prevention in equestrian jumping sports.

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Introduction

Maintaining the health of sport horses requires a fine-tuned balance between equipment, training management, and individual biomechanics. The hoof, as the biomechanical interface with the ground, plays a particularly central role. Phase 3 of the SHS study will investigate how the use of the SHS Performer, a bonded hoof protector, affects the movement behavior of sport horses compared to barefoot.

The two previous study phases have already provided important insights: In Phase 1, subjective feedback from the participating riders and horse owners revealed that horses with the SHS Performer were often happier and more willing to perform. Phase 2 was able to support these perceptions with objective movement data: Horses with the SHS Performer showed significantly improved values in stride regulation, force expenditure per stride, and lateral balance.

In Phase 3, the focus is now on the direct comparison of barefoot and performer conditions under controlled conditions in dressage and show jumping training. For this purpose, a valid set of biomechanical parameters will be measured, including thorax lift, stride ratio, balance in landing and turning, jump regularity, speed, and energy expenditure.
The use of bonded hoof protection systems is a relatively new but promising field. Studies such as those by Takahashi et al. (2022) show that bonded shoes exhibit reduced heel extension and other dynamic adjustments compared to nailed shoes, allowing conclusions to be drawn about shock absorption and comfort (Takahashi et al., 2022).

Studies on pressure distribution, for example by Gill et al. (2020), also show that modern hoof protection systems can make sole contact more homogeneous and potentially prevent overload-related damage (Gill et al., 2020).

Phase 3 of the SHS study aims to provide a differentiated picture of the effect of the SHS Performer on the functional movement of horses under sporting conditions. The goal is to provide objective decision-making support for selecting a suitable hoof protection system – and thus contribute to greater fairness, health, and performance in equestrian sports.

References:

Takahashi et al. (2022) Takahashi Y, Yoshihara E, Takahashi T. „Comparison of Heel Movement Between two Different Glue-on Type Shoes and Nailed Shoes in Thoroughbreds." Journal of Equine Veterinary Science, Juni 2022;113:103939. DOI:10.1016/j.jevs.2022.103939.
/ Key message:
The study found no significant differences in mediolateral heel extension between conventionally nailed and new, PU-based glue-on hoof boots in all gaits, except for trot, where the so-called Hanton boots showed slightly reduced extension (-14%) and increased contraction (+11%), but no change in overall movement. PubMed+4PubMed+4Mad Barn USA+4

Gill et al. (2020 Press/Hoof-Boot-Study) Gill J., Lynn G., Stratton T. "Evaluation of hoof pressure, contact area, and force using Fujifilm in booted and shod horses." Presented at the International Canine and Equine Locomotion Conference, 2020; later published as a poster/press by Western Kentucky University / Cavallo.
Source (Press Release / Article):
Gill et al. showed that Cavallo Trek Hoof Boots had significantly lower pressure in the hoof area and a larger contact area compared to steel shoes, indicating better pressure distribution and comfort on hard surfaces.

1 a) Practical Relevance

The performance of sport horses depends significantly on their movement economy and health. New hoof protection systems are gaining increasing importance in equestrian practice – especially glued hoof boots, which are used as an alternative to nailed shoes or the barefoot concept. Building on the results from Phase 1 (subjective feedback) and Phase 2 (initial data analysis of movement parameters).
Phase 3 focuses on the direct comparison of barefoot and Performer conditions. The goal is to investigate the objective biomechanical effects associated with the use of the SHS Performer compared to barefoot.

Fig. 1: Performer attached to the hoof, right: product images SHS

Why glued hoof boots?

Glued hoof boots are considered a modern, flexible alternative to nailed shoes. They allow:

- better shock absorption (e.g. through more flexible soles),
- reduced stress on the hoof wall,
- and a potentially more natural rolling motion of the hoof.

Studies show that glued shoes can significantly influence lateral and medial heel expansion. For example, Takahashi et al. (2022) showed that glued polyurethane shoes exhibited 14% reduced heel expansion and 11% increased heel contraction during trot compared to nailed shoes.

A 2023 study by Gill et al. also investigated the pressure distribution in glued shoes (e.g. Cavallo Trek Boots) and showed a significantly more homogeneous pressure load on the hoof sole compared to nailed shoes, with potential relevance for prevention and rehabilitation.
The bonded Performer fittings used by SHS are based on this principle – but with a sport-specific focus, such as maximum grip under high ground stress and during jumping.

Scientific approach

All measurements were performed using the Alogo Move Pro sensor, a validated, FEI-compliant technology that delivers high-precision biomechanical data based on inertial sensing and AI processing. [3,6,7]
The analysis was performed in Excel, R, and Python code, requiring a minimum of 3000 usable steps per condition.

Expectations & Meaning

The observations so far (Phase 2) indicate that horses with SHS Performer:

- show more regular trot and gallop steps,
- work more efficiently with reduced power,
- and potentially show fewer compensatory movements.

Phase 3 intends to investigate these findings using a controlled study design and expanded parameters. The results are intended to help provide objective decision-making bases for the use of bonded hoof protection systems in sport horses – both in training and competition.

Objectives Phase 3

Phase 3 of the study is designed as a controlled data collection.

The results of Phase 2 suggest that the SHS Performer has a positive impact on the movement economy of horses in flatwork. Both biomechanically (longer, more consistent strides with reduced power) and subjectively, there is an increase in comfort and efficiency.

These observations support the objective of Phase 3, in which even more detailed statements are to be made through a controlled study design and expanded parameters that become relevant in a sport context (including balance and jumping technique).

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Method

Study design

Phase 3 of the SHS study was designed as a controlled comparative study. Each participating horse-rider pair completed defined training sessions under two conditions:

- Condition 1: Barhuf
- Condition 2: SHS Performer (glued hoof protection)

The order of the conditions was randomly varied to minimise adaptation effects and fatigue. Each horse underwent comparable scenarios in both conditions, including flat work, gymnastics, and show jumping. The course corresponded to their age and the respective performance class, from 90 cm (E or Young Horse A) to 135 cm jump height (M/S*).

Participants

Eligible participants were sport horses in regular training, in good general health at the time of the study (confirmed by rider and veterinarian), and had been barefoot for at least one year. The sample included show jumping horses aged 4–10 years.

Per horse / condition:
- min. 2 Flatwork-Sessions
- min. 2 Course-Sessions

Rider, equipment, and riding arena conditions remained constant between conditions.
No changes to bit, saddle, boots, spurs, etc. between conditions.

Participant

Eligible participants were sport horses in regular training, in good general health at the time of the study (confirmed by rider and veterinarian), and had been barefoot for at least one year. The sample included four show jumping horses aged 4–10 years.

Two participants dropped out for organisational reasons, and one participant was excluded due to the occurrence of lameness.

	Gender	**Age**	**Performance Level**	**Stable**		
TN 1	gelding	10	130/140 cm (M/S*)	vdB SH		
TN 2	mare	6	100 cm (A)	ProHorse		
TN 3	gelding	9	115 cm (A **)	CJL		
TN 4	gelding	4	Young Horse	Stal Egberink		
TN 5	*mare*	*4*	*Young Horse (4y)*	*Stal Egberink*	*drop out 1*	*lost PF*
TN 6	*mare*	*4*	*Young Horse*	*Hazan*	*drop out 2*	*compliance*
TN 7	*mare*	*4*	*Young Horse*	*Hazan*	*drop out 3*	*compliance*

Table 1: Participants and dropouts

Fig. 2: Jumping course on sand – textile floor (Locations: HV Rjdbodem, Sander Geerink Sporthose / Stal Egberink)

Measurement technology
The movement data were collected using the scientifically validated Alogo Move Pro sensor. This sensor was attached to the girth (front, median position) in accordance with FEI regulations and records the three-dimensional movement of the horse's body using GNNS and IMU (inertial sensor) technology with high temporal resolution (200 Hz).

Parameters collected
Environmental parameters (e.g. temperature)

- [STRIDE] Step parameters in all gears (e.g. step length)
- [JUMP] Jump parameters (e.g. take-off angle)
- Balance parameters (e.g. lateral balance on the paths)
- Analyseparameter (e.g: Stride Ratio)

For each condition, at least 3000 valid gait parameters were collected per horse.

Fig. 3: Alogo Move Pro sensor attached to the saddle strap. Based on GNSS and IMU technology.

Data Collection & Documentation

The measurement was carried out by the rider himself using the Alogo app, after instruction.

Each session was documented:

- Horse
- Discipline

All data was transmitted to the CJL Equine analysis team immediately after collection and stored centrally.

Data Preparation & Analysis

The data was processed using Excel and R. The following steps were followed:

Data cleansing: Removal of faulty steps or sessions with disruptive factors

1. Aggregation of at least 4 data sets / horse for step and jump analysis

Segmentation: Classification into pace types (trot, canter, jump)

1. Segmentation: Jump, paths between jumps
2. Segmentation: Approach (5 strides) – Jump – Landing (5 strides)
3. Segmentation landing step (ID 1)

Aggregation: Calculation of means/medians and standard deviations per parameter and condition

1. Correlation analysis

Comparative analysis:

- intra-individual (barefoot horse vs performer)

interindividual (group comparison)

  - Statistical analysis

- Interpretation with reference to functional relationships

Statistical Analysis

A pragmatic, data-centric approach was chosen for the analysis of biomechanical parameters in Phase 3 of the SHS study. The evaluation is carried out on an individual animal basis with the aim of identifying robust differences between barefoot and performer hoof protection conditions.
The following steps define the statistical process:

1. Analysis Logic – Intra-Individual Comparisons The data analysis is carried out within each horse. Each horse completes at least two sessions under barefoot and performer conditions. The defined analysis parameters are calculated for each session. Mean or median values are used depending on the distribution.

2. Checking the data distribution The distribution shape is checked for each parameter:

- Visual control (histogram, boxplot)
- Shapiro-Wilk test, if sufficient values are available ($n \geqslant 8$)

3. Choosing the appropriate test procedure
For normally distributed data:
→ t-test for paired samples (barefoot vs. performer)
For non-normally distributed data:
→ Wilcoxon signed-rank test or descriptive comparison using median and range
For small sample sizes ($n \leqslant 5$):
→ No significance test, but interpretative evaluation based on variance, deviation and effect size

4. Comparison parameters for each analysis type
Metric parameters with uniform distribution
→ Mean (MW) and standard deviation (STD)
Parameters with asymmetric distribution or risk of outliers
→ Median, range and, if applicable, interquartile range (IQR)

5. Visualization
Bar charts with error bars (SD or range)
Line plots for temporal trends across sessions
Boxplots for displaying non-normally distributed parameters

6. Assessment of Relevance: Significance is assessed at $p < 0.05$. In cases without a significance test, interpretation is based on the magnitude of the effect (e.g., % deviation), direction of change, and consistency across sessions.

Phase 3: Parameter

These parameters are systematically quantified and serve as key figures for the scientific evaluation of the comparison between Performer and Barefoot

They enable a detailed analysis of how the hoof protection system affects movement, allowing for targeted identification of potential improvements.

Parameter	Category	Nr in Report
Stride Length	Heath & Performance	9
Stride and Jump Force	Health	2
Energy	Performance	3
Gait Regularity in Trot	Health	5
Gait Regularity Canter	Health	6
Stride Ratio Index	Health & Performance	4
Balance Longitudinal	Performance	7
Long. Balance Approach	Technique	11
Lat. Balance Approach	Technique	12
Stride Length Landing	Technique & Performance	15
Longitudinal Balance Landing	Technique	16
Lateral Balance Landing	Technique	17
Speed Evolution	Performance	10
Take-Off Angle	Technique	13
Laterale Balance on Ways	Performance	8
Jump Regularity	Technique	14
Anomalies	Health	1

Table 2: Overview of analysis parameters:

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Explanations of the Analysis parameters in a Practical Context

a] Health

Anomalies
Machine Learning Algorithm, trained on locomotion pattern of lame / healthy horses

- This indicator is used to determine in advance whether the horses being examined are "healthy" and can be used for sport examinations. The resulting fitness index must be above 41%; below this value, the horse is excluded from the examination.

.Energy
A composite parameter that correlates various motion parameters.

- Used to assess motor expression and willingness to perform.

Siehe: Chateau et al. (2010), "A kinematic and energetic comparison of dressage and jumping horses"

Trot Regularity
Measures how symmetrical the movements of the diagonal leg pairs are.

- Detecting asymmetries, early detection of lameness or subtle rideability problems.

Canter Regularity: Assesses the consistency of the three-beat canter – e.g., rhythm errors or uneven transitions.

- Relevant in case of fatigue, back tension or poor balance.

a] General Locomotion

1. Stride Length
The horizontal distance a leg covers during one step – from the moment the foot touches down to the moment it lands again.

- Assessment of looseness, economy of movement and spatial reach.

2. Stride Force
A measure of the vertical acceleration when taking off – the higher, the more powerful the push-off.

- A low value may indicate fatigue or protective posture.

3. Energy
A composite parameter that correlates various motion parameters.

- Used to assess motor expression and willingness to perform.

Siehe: Chateau et al. (2010), "A kinematic and energetic comparison of dressage and jumping horses"

c] Dynamics and Control

1. Stride Ratio
Relationship between stride height, stride length and duration – simplified: how much movement the body makes vertically in relation to the forward movement.

- Discipline-dependent. The ideal is a powerful but economical movement. Here, regularity was considered a quality criterion.

See: Pfau et al. (2005), "Gait analysis of trotting horses: Stride parameters and symmetry"

2. Lateral balance (on the paths between the jumps)
Evaluates the lateral inclination of the horse in turns or on lines with changes of direction.

- Significant deviations indicate balance problems, one-sided load shifting or a weak outer shoulder.

3. Longitudinal Balance (General)
Measures the fore/hind leg load distribution during movement.

- This is especially important for assessing the horse's carriage and carrying during the gallop. Foreleg heaviness can indicate fatigue or back problems.

4. Longitudinal balance in the landing
Indicates whether the horse lands evenly balanced after a jump – or, for example, too much “on its nose” and how effectively it regains good balance after the jump.

- A sign of insufficient straightening in the jump or lack of power potential in the hindquarters.

b] Jumping and Transfer

Figure 4: Peerformer on sand – textile floor

6. Longitudinal Balance in the Approach

Assesses the body alignment before the jump – e.g., whether the horse is "on the forehand" or balanced.

- A forehand-heavy horse jumps flatter and with a higher risk of jumping errors and landing overload.

7. Lateral balance during Approach:

Assesses the lateral balance during approach – e.g., whether the horse falls onto one shoulder.

- Can indicate uncertainty in the line, incorrect aids or uneven load distribution

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6. Landing Stride Length

The distance of the first step after a jump – an indicator of forward flow, balance and relaxation.

- A comparatively shortened landing step often indicates cautious jumping, muscular fatigue or pain.

7. Speed Evolution over the Course

Analyzes the change in speed over time – shows whether the horse is moving at a constant pace, accelerating, or decelerating.

- A downward curve may indicate fatigue or mental tension; abrupt changes indicate control problems.

8. Take-off Angle

Indicates the angle at which the horse pushes off – i.e. how steep or flat it takes off.

- Shallow angles = risk of pole faults; steep angles = greater strain on the hindquarters. A steep take-off angle is considered an indicator of good show jumping technique.

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Results

Summary of Phase 2
Results Phase 3

Summary Phase 2

Comparison of data observations in two case studies:
Barefoot vs. Performer (Flatwork)

In Phase 2, two conditions on the same horse were analysed:

- Barefoot
- SHS Performer

Ergebnisse im Überblick (Durchschnittswerte)

Parameter	Barhuf	SHS Performer	Veränderung / Tendenz
Thorax Lift	0,16	0,18	↑ leicht erhöht
Trot Regularity	88,5	90	↑ verbessert
Canter Regularity	82,5	89	↑ deutlich verbessert
Stride Length	2,17 m	2,765 m	↑ deutlich verlängert
Stride Height	0,16 m	0,18 m	↑ erhöht
Duration	0,585 s	0,625 s	↑ etwas länger
Stride Ratio	0,274	0,288	↑ leicht erhöht
Stride Force	2,0 N	1,8 N	↓ reduziert

Data Table 1: Analysis Parameters Phase 2

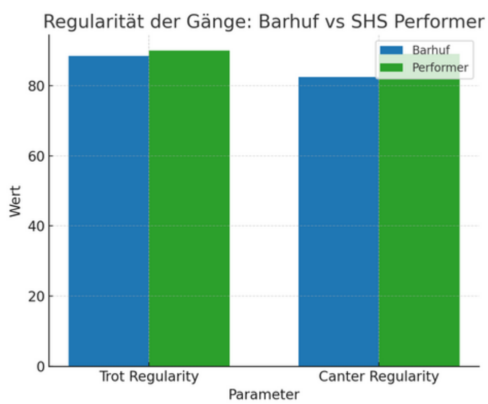

Chart 1: Comparison of gait regularity

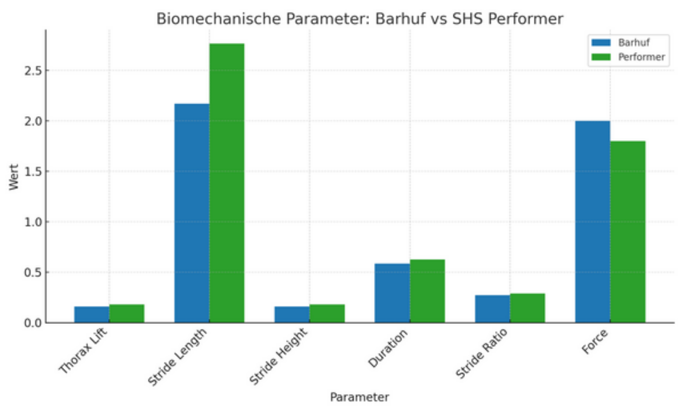

Chart 2: Comparison of analysis parameters

Interpretation

The most remarkable difference is in the stride length: With the Performer, the average stride length increased significantly by about 27 cm, which indicates a more unrestricted movement sequence.

At the same time, the force required per step (force) decreased by 0.2N – a sign of greater efficiency and lower stress.

- The regularity of the gaits (trot and canter regularity) improved significantly under performer condition.

The stride ratio (length-time ratio) and vertical dynamics (thorax lift, stride height) were also increased under the influence of performers, indicating a more active movement quality.

Conclusion Phase 2

The results suggest that the SHS Performer may have a positive impact on the movement economy of horses in flatwork. Both biomechanically (longer, more consistent strides with reduced power) and subjectively, indicating factors for an increase in comfort and efficiency are observed.

These observations support the objective of Phase 3, in which even more detailed statements are to be made through a controlled study design and expanded parameters (including balance and jumping technique).

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Phase 3 Results

Results

Comparison of Barefoot vs. Performer

Overview of Phase 3 Results.

Parameter	Einheit	Auswertung	Barhuf Ergebnis	Performer Ergebnis
Schrittlänge (Stride Length)	m	Avg + STD	2.75 ± 0.13	3.20 ± 0.82
Schrittkraft (Stride Force)	G	Avg	2,69	2,22
Energie (Energy)	kcal	Avg	4.19 ± 0.58	3.74 ± 0.98
Gangregelmäßigkeit im Trab	%	Wert	91	89
Gangregelmäßigkeit im Galopp	%	Wert	89	86
Stride Ratio	Index	Avg + STD	12.48 ± 2.1	13.71 ± 1.90
Balance Longitudinal (allg.)	°	Avg	0.44 F	2,24 B
Long. Balance Approach	°	Median / IQR / Range	6,05 / 10,38 / 31,63	4,1 / 9 / 45
Lat. Balance Approach	°	Median / Range / IQR	0,83 / 26,41 / IQR 8,15	0.8 F / 7.2 / ..
Schrittlänge Landung	m	Avg + STD + Range	2.11 ± 0.82 / 3.51 (1,16 - 4,67)	2.70 ± 0.10 / 0.40
Long. Balance Landing	°	Median / IQR / Range	0.8 F / 4.4 / 27	1,72 B / 7,53 / 31,63
Lat. Balance Landing	°	Median + Range	0.1 / 8.7	1,21 / 6,91
Tempoentwicklung (Speed Evolution)	m/min	Avg / STD + Min - Max / Range	346,11 ± 54,85 / 186–513 / 327	382 ± 21 / 325–415 / 90
Absprungwinkel (Take-Off Angle)	°	Avg / Min - Max / Range	20.7 / 10.0 – 29.9 / 19.9	33.08 / 23.66 – 44,70 / 21.04
Laterale Balance auf den Wegen	°	Median / Range / IQR	5 / 37,8 / 3,4	0.2 / 27.9 / 5
Sprungregelmaessigkeit	%	Avg	67	82
Anomalien	Index	Avg / Min - Max / Range	53 / 27 - 79 / 52	79 / 68 - 85 / 17

Data Table 2: Overview of the results Barefoot vs. Performer

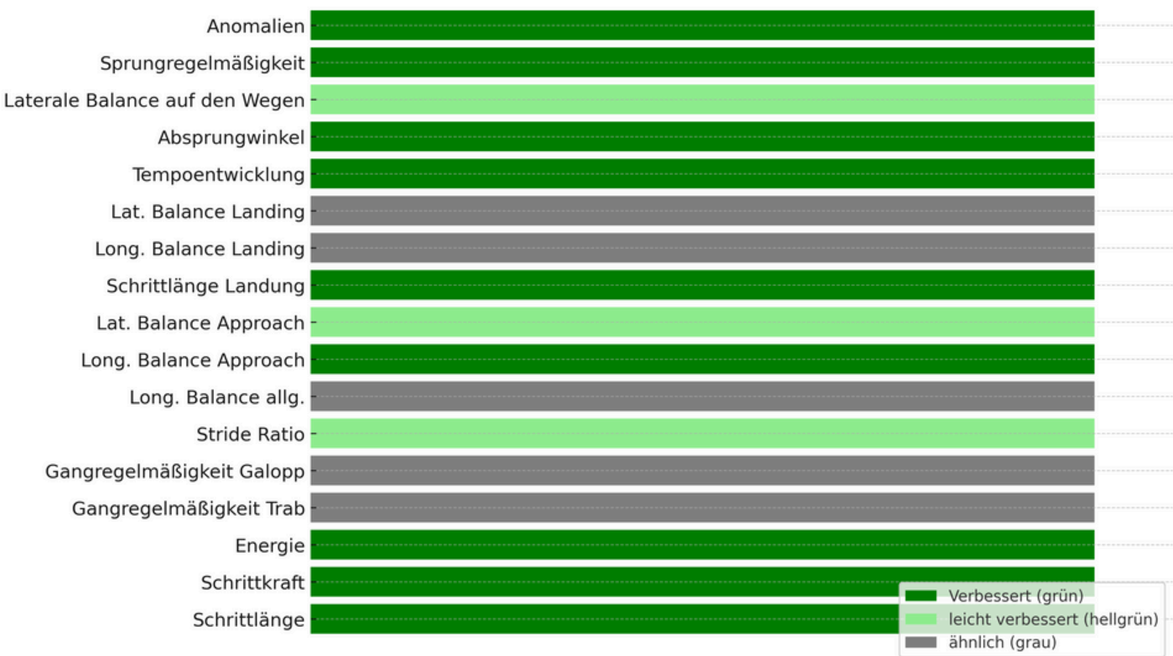

Chart 3: Visual representation of the effect of Performer Hoof Protection

Results: Health

1. Anomalies (%)

Anomalies are movement abnormalities identified by a machine learning algorithm. A high number of anomalies indicates discomfort or even lameness.

Horses with hoof protection show significantly fewer anomalies in the trot (26%).

Interpretation: A strong indicator for healthier movement

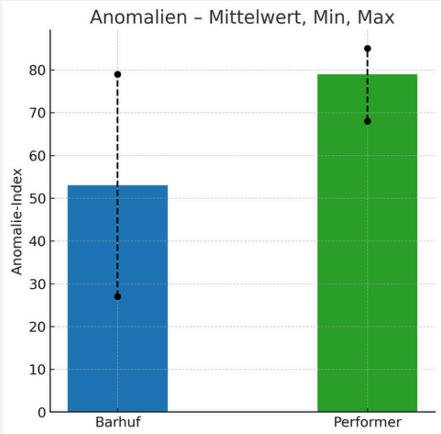

Chart4: Results Anomalies

Anomalies	Index	Avg / Min - Max / R	53 / 27 - 79 / 52	79 / 68 - 85/ 17

Data Table 3: Results Anomalies

2. / 3. Workload

The workload is determined by a) the step power in the gallop and the power in the take-off, and b) the required calculated energy requirement.

a) Effort required in Canter and Take-off
There is a significantly lower effort required in the jump and reduced energy expenditure in the steps.
b) Energy The horses use less energy for galloping and taking off.

Interpretation: Horses require less work with hoof protection. This may be related to improved technique and/or reduced stabilizing force (due to improved grip). [6,7]

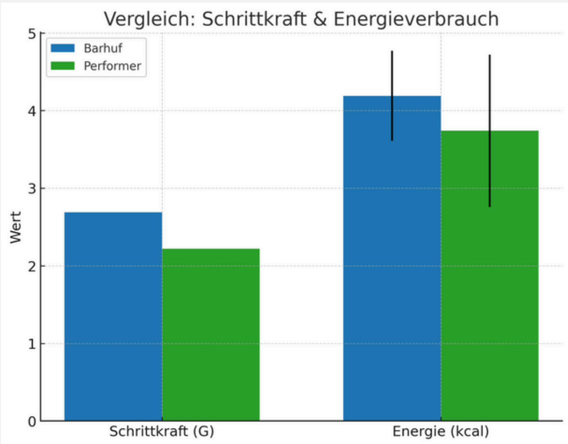

Chart 5: Results Strength and Energy

Schritt & Absprungkraft (Stride /Jump Force gemittelt)	G	Avg	269	222
Energie (Energy)	kcal	Avg	4.19 ± 0.58	3,74 ± 0.98

Data Table 4: Strength and Energy Results

4. Stride Dynamic in Canter

The stride ratio uses the thorax lift (also stride height), stride length and the duration of the stride. An increase in the Stride Ratio Index from 12.48 to 13.71 indicates a more dynamic footfall in horses with hoof protection. [1, 2, 4, 5]

This is a particularly strong quality criterion in connection with the reduced energy consumption.

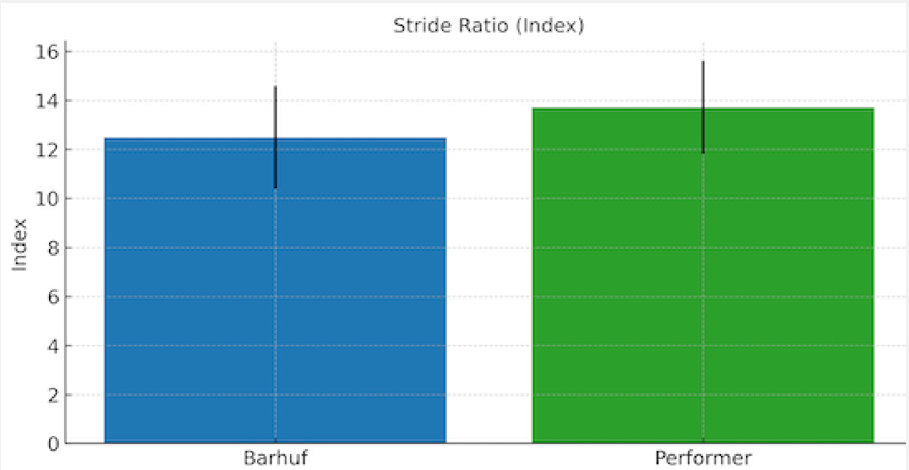

Chart 6: Stride Ratio Comparison

Stride Ratio	Index	Avg + STD	12.48 ± 2.1	13.71 ± 1.90

Data Table 5: Stride Ratio Results

5. / 6. Gait Regularity in Trot and Canter

The regularity of the gait (especially in the trot) indicates sound gait and is considered good in the Alogo analysis if it is above 85%. [2,6,5] It is good (over 85%) in both conditions.

Gait Regularity in Trot	%	Wert	91	89
Gait Regularity in Canter	%	Wert	89	86

Data Table 6: Regularity of gait in trot and gallop

Results: Performance

Balance on the Ways

7. Longitudinal Balance on the Ways
With Performer hoof protection, horses balance 3 degrees more on their hindquarters.
There is no difference in the longitudinal balance in both conditions in flatwork.

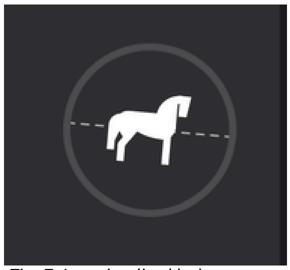

Fig. 5: Longitudinal balance

8. Lateral Balance on the Ways
A significant positive difference is evident in the balance on the trails, with a significantly reduced lateral balance (10 degrees). This means, in practical terms, that horses with hoof protection show more stability in turns.

Interpretation: Improved lateral stability can be explained by better grip.

Practical context: This can be an advantage in speed courses and jump-offs, and is helpful in developing safety and confidence in young or inexperienced horses. [1, 4, 8]

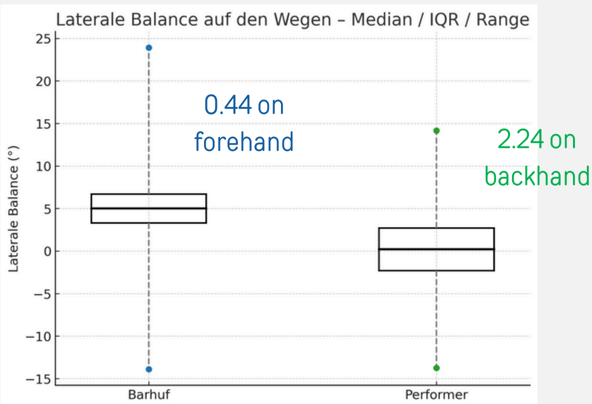

Chart 7: Balance Results

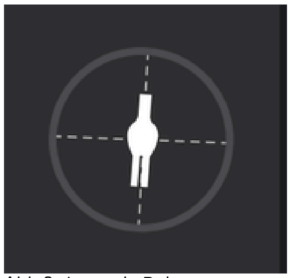

Abb 6: Laterale Balance

Longitudinal Balance	°	Avg	0.44 Front	2,24 Back
Lateral Balance on the Ways	°	Median / Range / IQR (Q3-Q1)	5 / 37,8 / 3,4	0.2 / 27.9 / 3.4

Data Table 7: Balance Results

9. Stride Length

The significant increase in stride length by an average of 45 cm in combination with an increased stride ratio is a strong indication of improved motor performance.

Causes of a reduced stride length can include discomfort, muscular restrictions, and fatigue. Since the change occurred immediately after the transition, this suggests discomfort in the barefoot horses. This hypothesis can be further supported by the reduced stride dynamics (= stride ratio) and an increased cadence.[1,2;4,6]

Stride length is an established biomechanical marker for assessing a horse's movement economy and suppleness (Clayton & Hobbs, 2017; Pfau et al., 2012). Studies using inertial sensor systems show that changes in stride length can also serve as a sensitive measure of fatigue (Rhodin et al., 2022) and asymmetric loading (Hobbs et al., 2014).

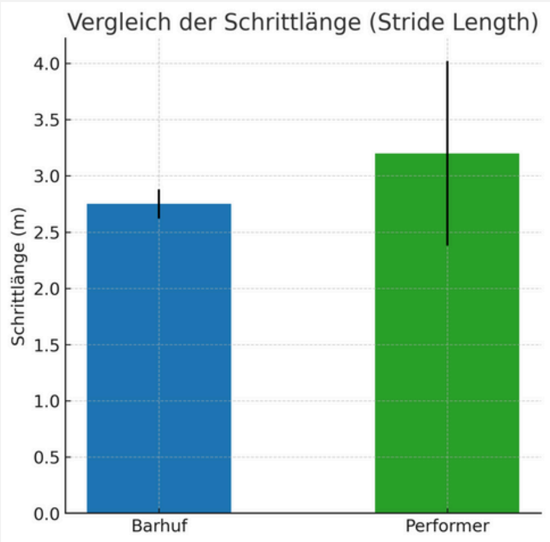

Chart 8: Stride length results

Schrittlänge (Stride Length)	m	Avg + STD	2.75 ± 0.13	3.20 ± 0.82

Data table: 8: Results stride length

10. Speed Evolution in the Course

With hoof protectors, the horses show significantly less variability in speed, with a base speed over 10% higher.
Barhuf: 346.11m/min
Performer: 382 m/min

Peaks of 513 m/min with high variability barefoot describe a more hectic, 'running' horse in the course.

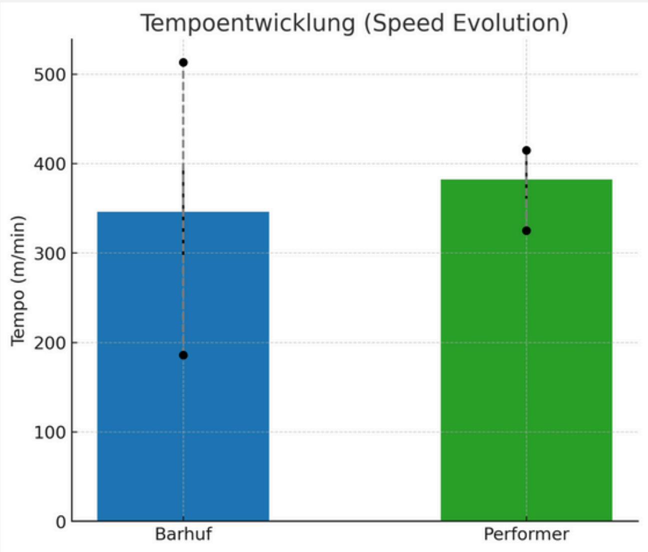

Chart 9 Results M, Range Tempo Development

Speed Evolution	m/min	Avg / STD + Min - Max / Range	346,11 ± 54,85 / 186–513 / 327	382 ± 21 / 325–415 / 90

Data Table 9 Results Tempo Development

Results: Jumping Technique

11. / 12. Technique in the Approach to the Jump

Longitudinal and lateral balance show no significant change when approaching the hoof protection.

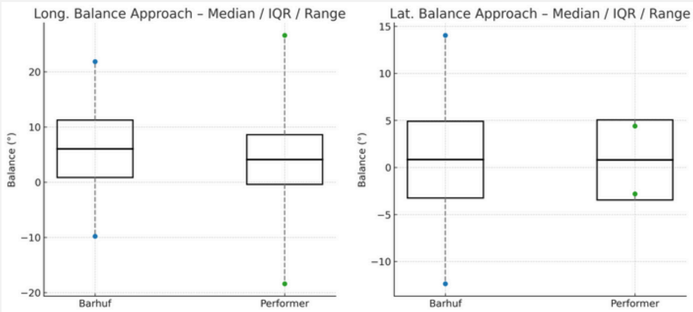

Chart 10: Balance Results

Longitudinal Balance	°	Avg	0.44 F	2,24 B
Laterale Balance on the Ways	°	Median / Range / IQR (Q3-Q1)	5 / 37,8 / 3,4	0.2 / 27.9 / 3.4

Data Table 10: Balance Results

13. Take-off Angle

A steep take-off angle is considered better than a flat one when considering show jumping horses. [5,8]

An average take-off angle of 13° steeper with hoof protection is a very significant change.

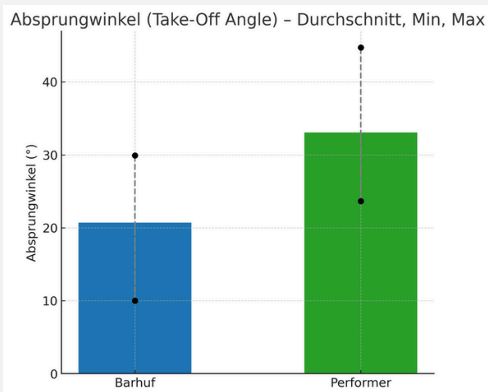

Chart 11: Results take-off angle

Take-Off Angle	°	Avg / Min - Max / Range	20.7 / 10.0 – 29.9 / 19.9	33.08 / 23.66 – 44,70 / 21.04

Data Table 11: Results Take-off angle

14. Regularity of Jumps

With hoof protection, the horses showed a 15% increase in regularity. This may be explained by the improved grip, but it could also be due to the horses' discomfort on their feet when barefoot.

Together with an average take-off angle of 13°, more balanced speed development and reduced speed peaks, the movement pattern of an improved jumping quality is shown with hoof protection

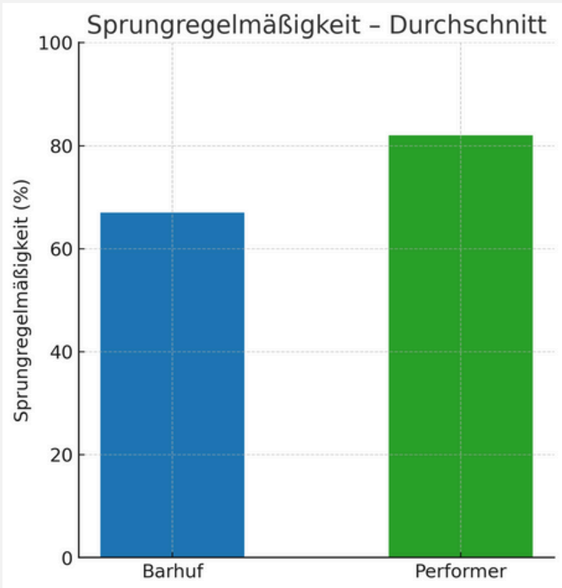

Chart 12: Results MW Comparison Jump Regularity

Sprungregelmaessigkeit	%	Avg	67	82

Data Table 12: Jump Regularity

Practical Context:
A regular jump is a sign of quality.
A young horse gains confidence when it can perform the jumps in a similar way.
An experienced horse shows by jumping regularly that it is up to the performance class.

15. / 16. / 17. Landing

- Stride Length of the Landing Step

The horses showed with hoof protection consistently significantly longer landing steps with an average of 59 cm and less dispersion, which indicates a more efficient, predictable movement pattern.
Barefoot, on the other hand, they show a high degree of variability – from short to excessively long – which may indicate inconsistency in power transmission or balance.

- Longitudinal Balance of the Landing Step

Barefoot, they tend to shift forward when landing (onto the forehand), with moderate spread. Performers show a slight backward lean (more hindquarter-heavy), which is often biomechanically more favourable for rapid reactivation after the jump – but with greater variability.
The higher range in both groups shows that there is generally a high fluctuation in the forward/backward tilt during landing.

- Lateral Balance in Landing

In both conditions, the horses are well balanced laterally in the landing.
However, the larger range (8.7°) barefoot indicates that occasionally larger lateral deviations occur.

Stride Length Landing (ID 1)	m	Avg + STD + Range	2.11 ± 0.82 / 3.51 (1,16 - 4,67)	2.70 ± 0.10 / 0.40
Long. Balance Landing (ID 1)	°	Median / IQR / Range	0.8 F / 4.4 / 27	1,72 B / 7,53 / 31,63
Lat. Balance Landing	°	Median + Range	0.1 / 8.7	1,21 / 6,91

Data Table 13: Landing Technique

Practical context:

This correlates with the generally improved stride length and jumping technique. The horses thus demonstrate an improved landing, which, in addition to the performance aspect, means a reduced risk of injury to the forelegs.

References

Clayton, H. M., & Hobbs, S. J. (2017). The role of biomechanical analysis in equine locomotion research: Past, present and future. Equine Veterinary Journal, 49(5), 560–568. https://doi.org/10.1111/evj.12734
Pfau, T., Spence, A., Starke, S., Ferrari, M., & Wilson, A. (2012). Limb coordination and variability patterns in horses with naturally occurring lameness. Equine Veterinary Journal, 44(6), 556–560. https://doi.org/10.1111/j.2042-3306.2012.00568.x
Keegan, K. G., Wilson, D. A., Kramer, J., Reed, S. K., Yonezawa, Y., Maki, H., ... & Pai, P. F. (2011). Comparison of a body-mounted inertial sensor system-based method with subjective evaluation for detection of lameness in horses. American Journal of Veterinary Research, 72(9), 1133–1138. https://doi.org/10.2460/ajvr.72.9.1133
Hobbs, S. J., Weller, R., & Clayton, H. M. (2014). Assessment of ground reaction force and centre of pressure parameters in the trotting horse: A review. Equine Veterinary Journal, 46(6), 700–708. https://doi.org/10.1111/evj.12247
Chateau, H., Degueurce, C., Denoix, J.-M., & Biau, S. (2006). Three-dimensional kinematics of the equine interphalangeal joints: Articular motion in the sagittal, frontal, and transverse planes. Equine Veterinary Journal, 38(Suppl. 36), 649–653. https://doi.org/10.1111/j.2042-3306.2006.tb05612.x
Rhodin, M., Roepstorff, L., French, A., Keegan, K. G., Pfau, T., & Weishaupt, M. (2022). Inertial sensor-based stride characteristics and symmetry indices in horses before and after induced fatigue. Equine Veterinary Journal, 54(1), 96–104. https://doi.org/10.1111/evj.13448
Burger, D., van Weeren, R., van der Kolk, J., & Pfau, T. (2023). Identifying signs of fatigue in eventing horses based on biomechanical parameters measured with inertial sensors. Equine Veterinary Education. https://doi.org/10.1111/eve.13916
Chateau, H., Holden-Douilly, L., Falala, S., Robert, C., Biau, S., Camus, M., ... & Ravary-Plumioen, B. (2013). Kinetics and kinematics of the forelimb in horses circling in a round pen. Equine Veterinary Journal, 45(5), 552–556. https://doi.org/10.1111/evj.12036

These sources cover the following parameters:

- Stride Ratio und Stride Length: [1], [2], [4]
- Gait Regularity and Sensor Methodology: [3], [6], [7]
- Jump Mechanics (Take-Off Angle, Jump Force): [5], [8]
- Balance lateral and longitudinal (also in curves): [1], [4], [8]
- Energy and fatigue: [6], [7]

CJL SPORT HORSE MONITORING

Appendix

Stride Ratio Explanation

Stride Ratio = (Stride Length×Stride Duration)/ Stride Height

A higher value means more vertical movement relative to forward movement → possibly less economical.
A low value indicates a "flat, expansive" stride – often more efficient, but also less dynamic.

This definition is common in horse gait analysis (similar to: Pfau et al., 2005), but may vary slightly depending on the source.

Is the calculation of the standard deviation (STD) for stride ratio statistically meaningful?

Yes, under the following conditions:
The aim is to characterize the variability within a session:
Then the standard deviation of the stride ratio over many individual steps provides valuable information about the consistency of movement – even if the distribution is not strictly normal.
The stride ratio is a continuous numerical parameter:
This fundamentally justifies the use of standard deviation as a measure of dispersion.
You interpret the STD descriptively, not inferentially:
That is, you describe how evenly (or variably) a horse moves, not whether the difference from another horse is "significant."

Restrictions:
Non-normally distributed data:
If you want to make a group comparison (e.g. barefoot vs. performer), you should better use median + IQR (interquartile range) or check beforehand whether a normal distribution exists (e.g. with Shapiro-Wilk).
Outlier sensitivity:
Since the stride ratio is calculated using three parameters (height, length, duration), it can be sensitive to outliers → possibly smoothing or using robust methods.

Conclusion:
For an intra-individual description like in your Phase 3 study, the average + STD of the stride ratio across all kicks per session is absolutely acceptable and common.

Analysis Process

1. Data preparation
a. Prepare files
Strides dataset: Contains distances between jumps
Jumps dataset: Contains approaches, jumps and landings
Statistics data set: Contains control parameters (e.g. duration, number of jumps)
b. Column cleanup (all numeric fields):
Remove units like "m", "ms", "cm", "kcal", "°" from all columns
Replace decimal commas with periods
Convert all columns to float
If necessary, filter Gait = "Canter" for specific analyses

2. Control parameters (from statistics and jumps file)

- Duration (min)

Distance (m)
Average speed (m/min)
Cadence (calculated: number of canter strides / time)
Number of jumps (rows with value in "Jump height (m)")

3. Analysis parameters (step-by-step evaluation)
A. General Locomotion (Strides file)
Stride Length (m): Mean + Standard Deviation
Stride Force (G): Average of "Strike power" (jumps)
Energy (kcal): Average and STD (Jumps)
Gait Regularity Trot/Gallop (%): Values from Statistics
Stride Ratio: Outlier correction, calculated as → MW & STD
B. Jump & Transition (Jumps-Datei)
Long Balance Approach: Median + range of ID -5 to -1
Lat. Balance Approach: Median + range from ID -5 to -1
Long Balance Landing: Median + range from ID 1 to 5
Lat. Balance Landing: Median + span from ID 1 to 5
Jump Take-Off Angle (°): Average, Min, Max, Range (jumps only)
Landing Stride Length (m): MW, STD, Range aus ID 1
C. Dynamics & Control (Strides file + Jumps)
Balance in the curve (Strides – Lateral Balance): Median, STD, Range, IQR
Speed Evolution (Avg Speed, jumps only): Average, STD, Min, Max

4. Statistical interpretation
For non-normally distributed parameters: Use median + range or IQR instead of mean + STD

5. Presentation of results
Overview table in Excel with columns: Parameter | Unit | Evaluation | Barefoot Result | Performer Result

Code

```
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from scipy.stats import ttest_rel, wilcoxon, shapiro

# Load the dataset
df = pd.read_excel("Single_Horse_Data_Barefoot_vs_Performer.xlsx")

# Initialize result container
results = []

# Plot style
sns.set(style="whitegrid")

# Create one plot per parameter
parameters = df["Parameter"].unique()

for param in parameters:
    # Subset and pivot
    df_param = df[df["Parameter"] == param]
    df_pivot = df_param.pivot(index="Horse", columns="Condition", values="Value")
    barefoot = df_pivot["Barefoot"]
    performer = df_pivot["Performer"]
    diff = performer - barefoot

    # Normality test
    p_shapiro = shapiro(diff).pvalue
    normal = p_shapiro > 0.05

    # Statistical test
    if normal:
        stat, p_value = ttest_rel(performer, barefoot)
        test_type = "Paired t-test"
    else:
        stat, p_value = wilcoxon(performer, barefoot)
        test_type = "Wilcoxon"

    # Store results
    results.append({
        "Parameter": param,
        "Mean Barefoot": round(barefoot.mean(), 2),
        "Mean Performer": round(performer.mean(), 2),
        "p-value": round(p_value, 4),
        "Significant (<0.05)": p_value < 0.05,
        "Test Used": test_type,
        "Normal Diff": normal
    })

    # Plot
    plt.figure(figsize=(6, 4))
    for horse in df_pivot.index:
        plt.plot(["Barefoot", "Performer"],
                 [df_pivot.loc[horse, "Barefoot"], df_pivot.loc[horse, "Performer"]],
                 marker="o", linestyle="-", label=horse)
    plt.title(f"{param}\n{test_type}, p = {p_value:.4f}")
    plt.ylabel("Value")
    plt.xlabel("Condition")
    plt.tight_layout()
    plt.grid(True)
    plt.show()

# Create results DataFrame
df_results = pd.DataFrame(results)
print(df_results)
```

Code

import pandas as pd import matplotlib.pyplot as plt import seaborn as sns from scipy.stats import ttest_rel, wilcoxon, shapiro

- # Load the dataset df = pd.read_excel("Single_Horse_Data_Barefoot_vs_Performer.xlsx")

- # Initialize result container results = []

Plot style sns.set(style="whitegrid")

- # Create one plot per parameter parameters = df["Parameter"].unique()

for param in parameters:
# Subset and pivot df_param = df[df["Parameter"] == param] df_pivot = df_param.pivot(index="Horse", columns="Condition", values="Value") barefoot = df_pivot["Barefoot"] performer = df_pivot["Performer"] diff = performer - barefoot

Normality test p_shapiro = shapiro(diff).pvalue normal = p_shapiro > 0.05

Statistical test if normal:
stat, p_value = ttest_rel(performer, barefoot) test_type = "Paired t-test" else:
stat, p_value = wilcoxon(performer, barefoot) test_type = "Wilcoxon"

Store results results.append({ "Parameter": param, "Mean Barefoot": round(barefoot.mean(), 2), "Mean Performer": round(performer.mean(), 2), "p-value": round(p_value, 4), "Significant (<0.05)": p_value < 0.05, "Test Used": test_type, "Normal Diff": normal })

# Plot plt.figure(figsize=(6, 4)) for horse in df_pivot.index:
plt.plot(["Barefoot", "Performer"], [df_pivot.loc[horse, "Barefoot"], df_pivot.loc[horse, "Performer"]], marker="o", linestyle="-", label=horse) plt.title(f"{param}\n{test_type}, p = {p_value:.4f}") plt.ylabel("Value") plt.xlabel("Condition") plt.tight_layout() plt.grid(True) plt.show()

Create results DataFrame df_results = pd.DataFrame(results) print(df_results)